Search for TeV Counterparts of Gamma-Ray Bursts with the HEGRA Experiment

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The HEGRA experiment is an air shower detector system for the study of neutral and charged cosmic rays in the energy range between 500 GeV to 10 PeV. Here we give an overview of how the HEGRA detector is used to search for TeV γ-radiation associated with Gamma-Ray Bursts (GRBs) registered with the Burst And Transient Source Experiment (BATSE) on board the Compton Gamma-Ray Observatory. Furthermore, results of an archival search for GRB radiation above 15 TeV carried out with the HEGRA air shower arrays are shown. We conclude with a summary of the search activities planned for the future.

1 Introduction

Despite the fact that Gamma-Ray Bursts (GRBs) have been known for more than 25 years their physical origin, energy and distance scale remain unsolved.[1] Counterparts at any wavelength would help to clarify the situation. The data taken with the two instruments BATSE[2] and EGRET[3] on board the Compton Gamma-Ray Observatory indicate that TeV counterpart observation is possible:

- Extrapolations of some of the BATSE[4] and EGRET[5] spectra yield large TeV fluxes which could be registered with high significance by present day air shower experiments.
- EGRET has observed photons with energies up to 18 GeV.[6]

Also several model scenaria of burst origin (e.g. the fireball scenario[7] or the scenario of evaporating black holes[8]) predict TeV emission. TeV counterpart observations would impose limits on the GRB distance scale because the intergalactic infrared radiation field limits the mean free path of TeV photons to distances of $\approx$ 100 Mpc.[9,10] Moreover TeV detection would reduce the number of possible emission mechanism models.

In this contribution we describe the searches for TeV counterparts of GRBs performed with the HEGRA detector system (La Palma, 28.8°N, 17.9°W, 2200 m above sea level). The experiment [11] covers a system of 6 Cherenkov telescopes, an array of 245 scintillation counters, an array of 72 wide angle Cherenkov counters called "AIROBICC" and an array of 17 Geiger towers. The searches can be divided into two classes:

1. **Searches in archival data:** Due to the large field of view of the air shower arrays of >1 sr, GRBs occur inside the field of view of the arrays at a rate of ≈25 per year. TeV radiation in coincidence with, before and after the GRB detection by BATSE can be searched for.
2. **Follow up observations:** The Cherenkov telescopes have a small field of view of 5 msr. A few minutes after a BATSE burst detection the BACODINE [12] (BATSE Coordinate Distribution Network) distributes preliminary burst coordinates via Internet. By slewing the Cherenkov telescopes immediately towards the burst direction, follow up observations are started within only a few minutes after a BATSE burst detection.

In Section 2 an overview of the TeV counterpart searches is given. The results of an archival search performed with the extensive air shower arrays are described in Section 3. The activities planned for the future are summarized in Section 4.
Recent searches for TeV counterparts with other detectors which did not yield convincing evidence for TeV GRB emission can be found in Aglietta et al., 1992 [13], Alexandreas et al., 1994 [14], Allen et al., 1995 [15], Amenomori et al., 1995 [16], Connaughton et al., 1995 [17] and Kieda et al., 1995 [18].

2 Overview of the Counterpart Searches Performed with the HEGRA Detector

The Search in Archival Data with the Air Shower Arrays

The scintillator array [19] registers secondary particles created by energetic primaries in the atmosphere. The array of wide angle Cherenkov counters AIROBICC [20] samples the atmospheric Cherenkov light created by the secondary particles. The scintillator array (number in brackets refer to the AIROBICC array) is characterized by a detection threshold for primary photons of 20 TeV (15 TeV), a mean angular resolution of $\sigma_{63\%} = 0.9^\circ (0.34^\circ)$ and a duty cycle of 0.95 (0.1) and is operational since 1989 (1992). Gamma/hadron separation information can be inferred by combining the information measured with scintillator and AIROBICC array [21] or by using the data taken with the array of Geiger towers [22].
Since the launch of the Compton Gamma Ray Observatory in January 1991 until June 1996 some 140 BATSE GRBs occurred within the field of view of the HEGRA arrays. In a first pioneering study TeV emission from 82 GRBs registered by BATSE between January 1991 and April 1994 was searched for in archival scintillator array data. [23] The search centered on the registration of emission coincident with the keV/MeV radiation measured by BATSE. No positive evidence was found but 90% confidence level upper limits on the coincident integral flux above detection threshold

energies of $\approx$50 TeV between 10^{-9} cm^{-2}s^{-1} and 10^{-7} cm^{-2}s^{-1} could be established. Recent work has focused on the analysis of BATSE GRBs recorded after April 1994 with extended and optimized methods. We have searched for coincident emission as well as for short and long time emission in the hours preceding and following a burst (see Section 3). The search sensitivity has been increased by optimizing the methods for small number statistics and by exploiting gamma-hadron separation information. [24] In a related study, short time TeV excesses independent of BATSE GRBs are searched for. [25] In another approach [26] delayed TeV radiation is searched for which could originate from EeV burst particles initiating particle cascades and thus TeV photons in interactions with the 2.7°K radiation background [27].

The Follow Up Searches with the System of Cherenkov Telescopes
Cherenkov telescopes measure the atmospheric Cherenkov light created by extensive air showers. [28] HEGRA has operated two telescopes, the first one [29] since 1992 and the second one [30] since 1994. During this year the system is being extended to its planned full scale. End of 1996 the installation of the full HEGRA telescope system will be completed and will consist of one "prototype telescope" and 5 "system telescopes". [31] A single system telescope is characterized by a detection threshold for inducing photons of 500 GeV, a mean angular resolution for individual events of $\sigma_{63\%}$ = 0.15°, a gamma-hadron separation with a photon acceptance of 0.55 and hadron rejection of 0.95, a field of view of 5 msr and a duty cycle of 0.1. [32]
The system has been used for follow up observations since February 1995. A search is initiated if a burst's intensity exceeds 1500 counts/sec (February 1995 - March 1996 the threshold was set to 2500 counts/sec), which corresponds to a BACODINE position uncertainty of $\sigma \lesssim 10°$. Still, due to the telescopes' small field of view, the probability for a single telescope to observe the true GRB position is only 0.05. Between February 1995 and July 1996 three follow up searches were initiated on GRBs 950401, 960425 and 960528 (YYMMDD). Observations were started approx. 10min after the BATSE detections. The first two observations were carried out with one, the last observation with 3 telescopes. For all three GRBs the the Compton/Ulysses Interplanetary Network of Satellites IPN [33] has now issued more precise location estimates which show that the HEGRA telescopes did not observe the true GRB locations.

3 An Archival Search with the Air Shower Arrays

In this section the preliminary results of a search for TeV radiation in archival scintillator array and AIROBICC array data are described. Thirty four GRBs recorded with BATSE between 1993 and 1995 were studied. The locations and durations of eighteen bursts were taken from the 3B catalog and the data of thirteen bursts have been transmitted to us by the BACODINE facility. For each burst three searches were performed:

- A search for **coincident emission**, i.e. for radiation within the time interval BATSE registered 90% of the burst counts.
- A search for **short time emission** with 60 sec intervals, two successive intervals overlapping half a minute.

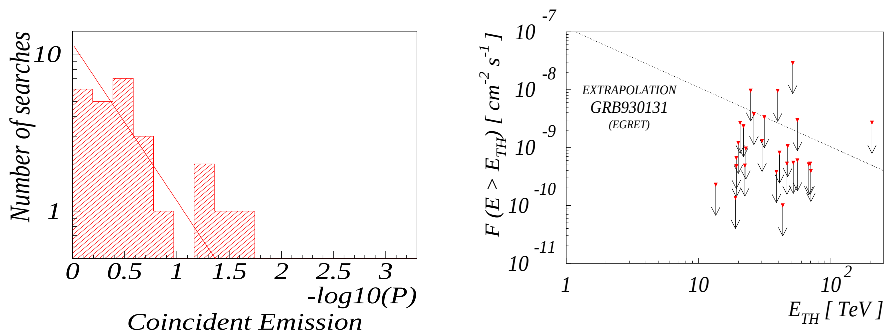

Figure 1: Results of the searches for coincident emission of 27 bursts. On the left side the distribution of the chance probabilities p is shown. The line depicts the distribution expected for the case that there are no counterparts in the data. On the right side the upper limits on the coincident flux (90% confidence level) versus the threshold energy for inducing photons are shown. The threshold energy is a function of the zenith angle of the location of a burst. To guide the eye an extrapolated GRB spectrum [34] is displayed.

- A search for **long time emission** with time intervals of a length of 2^i min for integer $i \geq 0$.

The intervals of the second and third search covered the time in which the burst location had been in the field of view of the HEGRA experiment ($\theta < 30°$). For each time interval either the $2\,\sigma$ error region given by BATSE or the smaller ring segment given by the Compton/Ulysses Interplanetary Network of Satellites were searched for emission. In order to exploit the better angular resolution of the HEGRA arrays in comparison to BATSE, grids of optimal search bins were used. Repeating the search with shifted grids ensured that a large fraction of about 90% of hypothetical source photons would fall inside one of the bins. With the trigger rate and the detector acceptance in horizontal coordinates the background was calculated [35] and Monte Carlo data were generated. A burst candidate was the most significant excess found in a search. With the help of the Monte Carlo data the **chance probability** p for the background to yield a burst candidate equally or more significant than the observed one was calculated.

The search for coincident emission was applied to 27, the search for short time emission to 26 and the search for long time emission to 23 out of the 34 bursts, depending on the position of a GRB in the local sky and on interruptions of the detector exposure due to calibration runs. The following results have been obtained:

- **Coincident emission:** In Figure 1 (left side) the chance probabilities p of the searches are shown. The observations are consistent with the background expectation. In Figure 1 (right side) the upper limits on the observed flux (90% confidence level) are shown. The upper limits are well within the region of extrapolated GRB spectra.

- **Short time emission:** A remarkable excess (Fig. 2, left side) was found for GRB 950701 (06:35 UTC). During one minute, 86 minutes before the burst

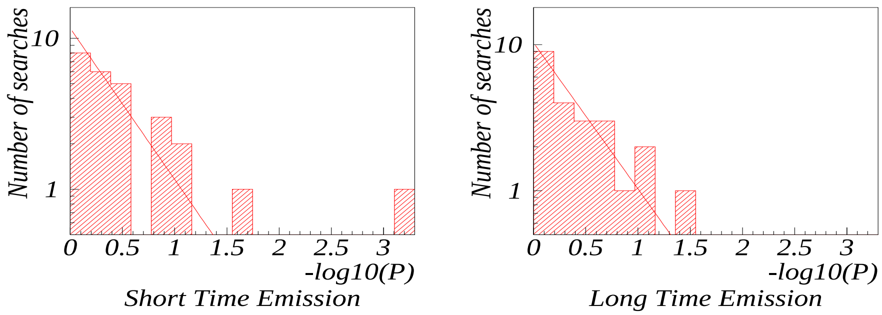

Figure 2: Distributions of the chance probabilities p for the searches for short and long time emission. The lines show the distributions expected if there are no counterparts.

triggered the BATSE detector, 12 events were observed from the burst direction where 1.7 were expected. The significance of the raw excess is 6σ. Taking into account all search bins in temporal and solid angle space the significance of this excess is 3.4σ.

- **Long time emission:** No significant excess has been found (Fig. 2, right side).

Altogether the 76 searches yield results which are consistent with a non-detection of TeV counterparts.

4 Future Activities

The described searches with the air shower arrays and the system of Cherenkov Telescopes will be continued.
The follow up searches will be extended:

1. Follow up observations will be performed not only with the Cherenkov Telescopes but also with the scintillator array. After a burst warning an "angle sensitive trigger" will lower the threshold condition of 14 counters in coincidence to 3 counters in coincidence, while only accepting showers from a 20°FWHM centered on the burst direction. By this means the energy threshold of the scintillator array is lowered from 20 TeV to 3 TeV while increasing the trigger rate only slightly.

2. Follow up observations will be initiated not only by BATSE via BACODINE but also by the instrument HETE which will be launched on October 1996. For this purpose a HETE receiver will be installed on the HEGRA site.

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